# Industrial Cleaning with ultra-clean water according to the Qlean-method – a case study of printed circuit boards

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**ABSTRACT**

The manufacturing industry today uses many kinds of chemicals in its cleaning processes. The industrial cleaners often contain some sort of degreasing chemical to clean parts and components before the main processes, for instance assembly or surface treatment. These types of cleaning methods are often expensive and involve hazardous handling of chemicals in manufacturing, as well as in the transportation of hazardous waste. In addition, the cleaning processes often use a substantial amount of energy for cleaning.

The aim of this paper is to explore how ultra-clean water cleaning, using a method called Qlean, can be applied in the manufacturing industry. In order to meet this aim, a case study was conducted at Flextronics, in Karlskrona, Sweden. The data for this research was collected through interviews and functional tests at different industries, which then was analysed further.

The results from this research show that using solvent-free industrial cleaning with ultra-clean water is beneficial from the perspectives of quality, environment and business. The quality improvement derived from using solvent-free industrial cleaning in the case of cleaning printed circuit boards was the most important benefit.

**Keywords:** Ultrapure, Degassed, Cleaner Production, Qlean, SOFIQ project.

## 1. INTRODUCTION

In today's fierce competition, manufacturers face many challenges to stay in business and prosper. One of these is the challenge of producing products without excessive harm to the environment. In general, there are two main activities that a manufacturing company usually focuses its environmental activities on: the production and the product. One strategy for focusing on the product is usually called ecodesign or Design for the Environment (DfE). This focus is especially important when much of the environmental impact occurs during the use phase. The other strategy of making the production more environmentally sustainable, sometimes called cleaner production, is the focus of this paper.

Many manufacturing companies, especially in Sweden, are dealing with their cleaner production issues through environmental management systems such as ISO14001 or The EU Eco-Management and Audit Scheme (EMAS). In those kinds of environmental management systems, the companies can set environmental targets such as how much resources to use (per unit produced) or how much environmental emissions the production process should have to air, water and soil. In an attempt to reduce environmental impacts from the manufacturing and to achieve continuous improvement, companies usually strive to find better production processes from economic and environmental perspectives. In addition, there are several companies today that have reached their allowed limit of chemical usage. This means that they are not allowed to increase their production volumes with present production processes due to their chemical usage. Thus, if one could reduce the amount of chemicals used in the process (per unit produced) the company could increase their production volumes and still stay within their limit of chemical usage.

The research for this paper was conducted on behalf of a Swedish research project, Solvent-Free Industrial Qleaning (SOFIQ). Within this project, the research team has focused on cleaning processes that reduce the usage of chemicals and energy in order to achieve environmental and economic benefits. This has been achieved by using an ultra-clean water type in industrial cleaning processes called Qlean. This cleaning method was developed by the company called Qlean Scandinavia AB (formerly named Servicestaden AB).

The Qlean-method is new way of cleaning without the use of chemicals such as detergents. The method has proven successful, for example, in the cleaning of building exteriors, electrical power transformers and transformer stations, and cameras in road tunnels. The procedure only requires spraying with low-pressure, thus better salvaging the paint yet removing dirt, oil and debris from various surfaces such as walls. Successful projects include the cleaning of the above-mentioned building exteriors and at Vadstena Castle, and tunnel walls and road signs of the Södra Länken tunnel system in Stockholm. [1]

Qlean Scandinavia AB has successfully deployed their cleaning method of using ultra-clean water in the applications described above. However, the company's product and methodology must be further developed in order to meet demands from the manufacturing industry. The Swedish manufacturing industry also sees Qlean Scandinavia's product as a good opportunity to tackle the existing and increasing environmental restrictions being placed on manufacturers within the European Union (EU). Hence, there is a mutual interest to explore and expand the cleaning methods of ultra-clean water in the Swedish manufacturing industry.

## 2. AIM

The aim of this paper is to describe how the Qlean-method can successfully be used within the manufacturing industry. In addition, a specific goal of this paper is to describe the benefits of the Qlean-method when cleaning printed circuit boards before being lacquered.

## 3. METHODOLOGY

The methodology for this research paper was manifold. The development of the ultra-clean water used in the Qlean-method was primarily performed at Qlean Scandinavia and was seen as a base of this research. Companies that may have a need for this kind of cleaning were contacted, and subsequently interviewed using semi-structured interviews, in order to understand their needs. The research methodology included field visits to potential industries and performing functional tests. Discussions with the potential customers were also conducted [2].

The environmental analysis presented in this paper is based on assumptions on the proposed technology. Greenhouse gas (GHG) emissions were calculated for a generic degreasing process using alkaline baths, which were then compared to the proposed technology outlined in this paper. The resulting GHG emissions were calculated in SIMAPRO, which is a life cycle assessment tool, and the generic data was derived from the Ecoinvent database (cf. Classen et al [3]). The analysis only studies the use phase of the processes; i.e., the infrastructure needed for the processes is not included.

## 4. ULTRA-CLEAN WATER

Research about the use of ultra-clean (sometimes known as ultra-pure) water for industrial cleaning is scarce. However, we have seen that research about the industrial application of ultra-clean water has been used for some time within the area of semi-conductor manufacturing (see e.g. Ohmi [4]). Researchers at the Department of Electronics at Japan's Tohoku University have conducted research on ultra-clean technologies, including the use of ultra-clean water within semi-conductor manufacturing. The manufacturing of semi-conductors requires an ultra-clean environment including ultra-clean technologies.

Within this research, ultra-clean water refers to water that it is completely free of by-products such as salt, lime, minerals and metals. The application of ultra-clean water on exterior walls can be in both low pressure and high pressure, depending on how sensitive the foundation is. Ultra-clean water not only loosens algae and exhaust fumes, it also acts equally well on grease and oil.

The function of ultra-clean water has not been studied within the SOFIQ project. However, a literature study has been conducted by Professor Bo Svensson from the Department of Water and Environmental Studies at Linköping University. He found that the reason that dirt and grease do not dissolve in ordinary water is due to the gases found in ordinary water, which prevent the water molecules from binding with the hydrocarbons in the dirt. The process of creating ultra-clean water primarily entails the removal of gases, resulting in a capacity for the ultra-clean water to loosen dirt and grease. These conclusions are based on the research results from a research group in Canberra, Australia who have studied this phenomenon since the beginning of this century. The chemical explanations to why the ultra-clean water dissolves dirt and oil can be found in the research from this group in Francis & Pashely [5] and Francis et al [6].

According to Qlean Scandinavia [1], cleaning with ultra-clean water is not only the most environmentally sound method on the market; it also has many other advantages, such as a very short drying time which can reduce the total cycle time of an operation. This means that a building cleaned according to the Qlean-method can be repainted within a shorter time [7].

## 5. THE SOFIQ PROJECT

The overall goals of the project are to reduce environmental effects on the manufacturing site, the amount of chemical emissions during manufacturing and the number of chemical transports from the facility. Improving the working environment within the industry and reducing the energy consumption as well as costs are additional goals.

In this project, we started out by interviewing potential customers to find out their needs and to see how interested they would be in changing their systems into something more environmentally friendly [2]. We found out that there are more problems than we thought with current systems, and the interest in trying new methods was huge. After this, we performed several tests at the customers' sites (see case studies below). Our next goal initially was to develop a functional prototype, which we did as well as installing and improving equipment at Flextronics in Karlskrona, Sweden. In order to measure how effective the Qlean-method is, we performed different tests at Linköping University, Akzo Nobel, ABB and Swerea/IVF. Most of these tests were conducted on products that had first been cleaned with ultra-clean water from Qlean Scandinavia, and then powder coated to see how the result compared to their ordinary cleaning system. The results showed that, in most cases, the ultra-clean water performed just as well as with their ordinary system.

In order to find out the potential of using the Qlean-method in the Swedish manufacturing industry, we visited companies to find out how well it would potentially work in their processes. The following describes our industrial progress.

*5.1. IonBond*

IonBond is an international leader in the highest quality thin-film coating technologies (e.g. PVD, PA-CVD, CVD). At IonBond we cleaned the products before coating, but corrosion before coating prevented a good result.

*5.2. ABB*

At the industrial robot manufacturer ABB, we compared products cleaned with ultra-clean water at low pressure with cold and hot detergent solutions at high pressure. The ultra-clean water wash, although significantly reducing the amount of oil, did not totally remove all the oil as in the high pressure wash. Thus, new tests are to be conducted with ultra-clean water and high pressure.

*5.3. Toyota Material Handling*

We performed functional tests on forklift trucks at Toyota Material Handling. Toyota's biggest problem is the large amount of chemicals used in this process, concerning both the general environment and the working environment. The first test turned out to be very good, and hence test equipment is to be installed.

*5.4. Blomberg & Stensson*

Functional tests on products were carried out before powder coating. When replacing the four cleaning steps with the Qlean-method, the results were equally good. Blomberg & Stensson is now in discussions with their customers (e.g. Scania and Toyota) for approval of this cleaning method. After that, equipment will be installed at their facilities.

*5.5. Volvo Buss*

At Volvo Buss in Gothenburg, we cleaned products before powder coating. They are very pleased with the results but are waiting for approval from management to proceed with more advanced tests.

*5.6. Akzo Nobel*

At Akzo Nobel in Malmö, we tested our system in comparison with Akzo Nobel's chemicals on products of Volvo Bus and Volvo Technology. These tests were then evaluated by Akzo Nobel in a report that showed the Qlean-method is as good a method as the chemicals. Akzo Nobel has now shown interest in offering their customers this cleaning method to use before blasting and powder coating their products.

After the initial industrial visits, the potential for implementation of the Qlean-method was studied, and it was decided to focus mostly on the case of cleaning printed circuit boards (PCBs) at Flextronics. The next section will deal more with the results of the industrial case of Flextronics

## 6. INDUSTRIAL CASE: FLEXTRONICS

In order to explore the potential of using the Qlean-method for cleaning PCBs before lacquering, a case study was conducted at a manufacturer of such boards, Flextronics. Flextronics was interviewed and has provided extensive data for the environmental calculations. As the global leader of Electronic Manufacturing Services (EMS), Flextronics provides design, manufacturing and value-added services to their worldwide customers covering all industries including IT and telecommunications [8].

During 2008 we installed a set of test equipment for cleaning PCBs. This test equipment set operated as our first demonstrator for using the Qlean-method in cleaning PCBs. Figure 1 show the mobile equipment used in this project.

**Fig. 1: The functional prototype used for testing the Qlean-method at Flextronics in Karlskrona, Sweden.**

We produced great test results and this led to the installation of permanent equipment in 2009 which is shown in Figure 2 below.

**Fig. 2: The installed equipment used for cleaning printed circuit boards according to the Qlean-method at Flextronics in Karlskrona, Sweden.**

The two main things to clean on the PCBs were fingerprints and flux stuck on the components from previous production steps. The equipment was installed

directly on the washing machine with the initial plan to clean 1/3 of the PCBs, with the remainder to be cleaned with traditional chemicals (detergents). To date, all the PCBs have been cleaned with the Qlean-method. Approximately 500,000 PCBs have been cleaned according to the Qlean-method thus far, and the method has been used for more than one year. Before this, more than 10% of the components were discarded and with this new Qlean-method, a 90% reduction in scrap was achieved. Today, Flextronics discards less than 1% using the Qlean-method. Currently, we are upgrading the system due to the production increase at Flextronics. The installation at Flextronics in Karlskrona, Sweden is shown in Figure 3.


**Fig. 3: The first installed application and usage of the Qlean-method within the electronic industry – cleaning of printed circuit boards.**

During the trial of the prototype cleaning equipment, it was found that the Qlean-method with ultra-clean water resulted in very good quality effects on the products being cleaned (in this case PCBs). The PCBs were less damaged by the ultra-clean water as they traditionally were when cleaned with detergents.

Another quality issue that Flextronics had with the traditional detergent cleaning method was that some of the detergent could get stuck in cavities due to the components' shape, as seen Figure 4. The hidden detergents could then, in a later stage of production and/or during use, leak out and damage the printed circuit board and/or other components. With the new cleaning method, the detergents are gone and the problem ceased. Another problem with the existing cleaning method was that sometimes the text on the components was damaged during the cleaning process. This problem does not occur when using the solvent-free industrial cleaning method.

*6.1 Environmental analysis*

One of the important goals with this project was also to find out how much improvement in environmental performance this new system can bring about so environmental benefits calculations comparing the Qlean-method with the ordinary method were carried out. Additionally, calculations were conducted at Flextronics concerning financial gains with the system (see Section 6.2, Economic analysis).

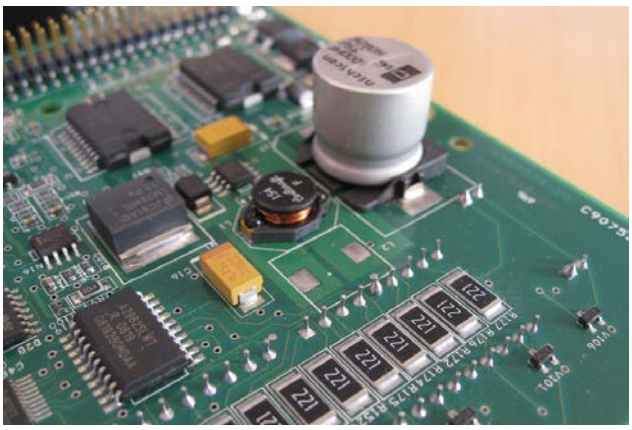

**Fig. 4: Example of a printed circuit board cleaned with the Qlean-method, showing components with shapes that detergents could get stuck on.**

The following paragraphs present the goals of the SOFIQ project and how they have been fulfilled in the industrial case at Flextronics.

*Goal 1: Less chemicals used in cleaning process*

The use of chemicals has been completely eliminated in the cleaning of PCBs. No additional liquids are added in the cleaning process other than the ultra-clean water.

*Goal 2: Better working environment*

The working environment for the employees has been improved due to the reduction in the handling and transportation of chemicals in the production facility.

*Goal 3: Reduction of hazardous waste*

Less amounts of hazardous waste are created when no chemicals are used in the cleaning process. The Qlean-method has eliminated the need for transport and treatment of hazardous waste from the cleaning facilities.

*Goal 4: Reduction of energy use*

The amount of energy used in the cleaning process was measured to be reduced by 30%. This was mainly due to the fact that the washing operation with the Qlean-method was conducted at room temperature, instead of the normal cleaning temperature of 60 degrees Celsius. In addition, the washing time was reduced from 8 to 2 minutes. The rinse sequence that follows the washing operation was also shortened from 7 to 5 cycles, as indicated in Table 1 below.

**Table 1: Overview of the conventional cleaning process and the new Qlean-method at Flextronics.**

| Cleaning step | Conventional method | Qlean-Method |
|---|---|---|
| Washing | 8 minutes at 60 ℃ | 2 minutes at room temperature |
| Rinsing | 7 cycles with deionized water | 5 cycles with ultra-clean water |
| Drying | 30 minutes at 65 ℃ | 30 minutes at 65 ℃ |

*Goal 5: Avoid upstream environmental pressure*

In the Flextronics case, all of the chemicals have been removed from the cleaning process. This means that all the production and transportation of the chemicals is avoided (Figure 5 (left)). One of the major advantages is that by introducing the Qlean-method, the amount of discarded PCBs in the production process has decreased significantly. There are indications that the amount of environmental impact avoided by the elimination of chemicals is by far the most important environmental achievement of the Qlean-method in the Flextronics case (Figure 5 (right)).

*6.2 Economic analysis*

From a business perspective, Flextronics will directly save money on the usage reductions of electricity and detergents. However, the quality aspects of cleaning according to the Qlean-method with ultra-clean water in their industrial cleaning process are trickier to estimate and calculate. Here, the economic figures are hard to quantify, and fluctuate depending on the cleaned components' importance (related to e.g. cost for component, repair and functionality) and the final product's customer value.

In the life cycle cost (LCC) calculations made in this project at Flextronics, it was found that the Qlean-method is three times less expensive than the conventional cleaning method with detergents [9]. This is mainly due to the conventional cleaning costs for detergents and higher use of energy. In addition, the Qlean-method results in a much better product. If the cost of discarded PCBs were to be included in the LCC, the Qlean-method would be even more profitable for Flextronics and its customers.

In the LCC, the unit of analysis was a fully-loaded washing machine with PCBs. The costs for investing in the washing machines were not included, since the same kind of washing machine is used for both alternatives. However, using the Qlean-method would not require such advanced washing machines as the conventional method does.

If it is possible to obtain greater customer satisfaction, it will improve the company's reputation and strengthen its brand. The customers of Flextronics will also enjoy increased reliability in the Flextronics products they purchase. In addition, quality improvement is the most important benefit that Flextronics can see with the use of solvent-free industrial cleaning for their PCBs.

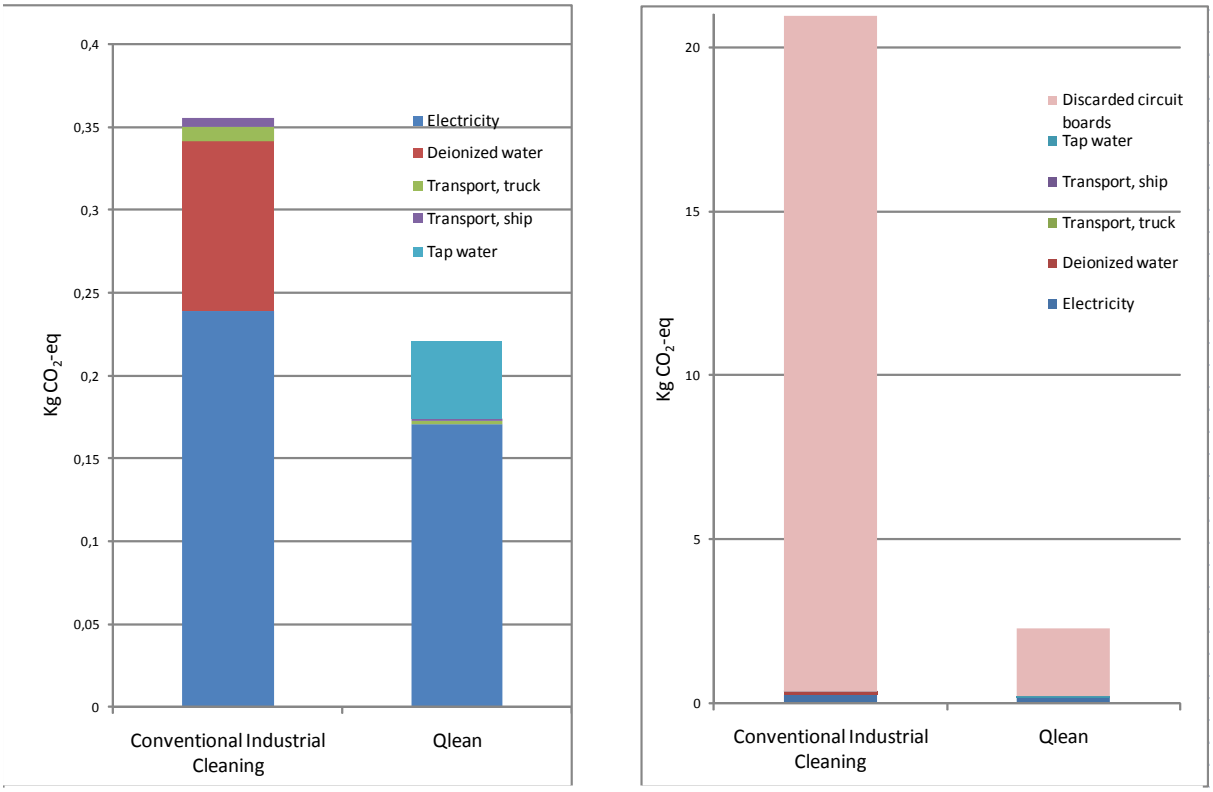


**Fig. 5: To the left, the climate gas emissions from the cleaning process in the Flextronics case. To the right, climate emission from the cleaning process including emissions from discarded boards in the Flextronics case.**

To summarize the industrial case where the Qlean-method has been installed with the equipment shown in Figure 2, we can conclude that the Qlean-method is successfully installed from both environmental and economic perspectives. This is mostly due to the fact the Qlean-method results in fewer discarded PCBs. Altogether, this means that the quality and technical lifetime have been extended with the new cleaning method. This provides customers with PCBs of a higher quality, and thus a higher degree of customer satisfaction.

## 7. CONCLUSION

This paper has presented a completely new method of cleaning without detergents which also works well in lower temperatures. The results of the SOFIQ project have been presented at several environmental conferences with good feedback. However, more research is needed from a chemical perspective to describe the chemical processes behind how the Qlean-method dissolves dirt and oil.

To conclude, in this paper we have described how the SOFIQ project found an industrial cleaning method called Qlean, which in the case of cleaning PCBs at Flextronics is a preferable option to conventional cleaning regarding the aspects of environment, quality and overall business.

## 8. ACKNOWLEDGEMENTS

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